Development of Sensors for Automotive Fuel Cell Systems

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Objectives

Develop technology and a commercial supplier base capable of supplying physical and chemical sensors required to optimize the operation of proton exchange membrane (PEM) fuel cell power plants in automotive applications.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- B. Sensors
- E. Durability

Approach

The team assembled for this project will perform the following tasks:

1. Obtain representative samples of physical parameter sensors currently available to meet the targets specified in the fuel cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program (HFCIT) Multi-Year R,D&D Plan (MYP).
2. Design and construct a facility for testing physical and chemical sensors under simulated reformer exit conditions.
3. Determine the suitability of state-of-the-art physical parameter sensors for the extreme environment of a PEM fuel cell power plant by testing them in a combination of laboratory and simulated fuel cell flow stream environments.
4. Assist the sensor manufacturers, where necessary, to modify their sensors to achieve the requisite performance and durability goals.
5. Modify baseline chemical sensing technologies to create sensors capable of measuring the gas concentrations listed in the HFCIT Multi-Year R,D&D Plan while operating in a PEM fuel cell environment.
6. Validate and document the performance and durability of the developed sensors by exposing them to a combination of laboratory and simulated fuel cell flow stream environments.
7. Install the developed sensors on a PEM fuel cell at UTC Fuel Cells (UTCFC) for final testing.

Accomplishments

- Designed and constructed physical and chemical sensor test facility for simulated reformer test gas stream.
- Developed software for continuous monitoring and operation of the test facility.
- Developed α-prototype H_2 safety sensor and began testing.
- Completed physical sensor survey and have obtained candidate sensors for evaluation.

Future Directions

- Evaluate physical sensors in United Technologies Research Center (UTRC) facility followed by tests at UTCFC on the S300 gasoline-fired reformer breadboard facility.
- Obtain electrochemical and micro electromechanical system (MEMS) chemical sensors and evaluate in UTRC and Illinois Institute of Technology (IIT) test facilities.
- Optimize sensor performance and reliability.
- Deliver sensor suite for testing at UTCFC gasoline-fueled reformer PEM cell facility.

Introduction

The present state-of-the-art in fuel cell power plant sensor technology is embodied in the UTC FC PAFC PC 25 and PEM S200 power plants. Sensors measuring all of the parameters defined in the HFCIT Multi-Year R,D&D Plan are utilized in designing and setting up these power plants. However, none of the chemical sensors and only a very few of the physical sensors are "on-board" the power plant, and only temperature and stack differential pressure, in the S200, are measured continuously for control purposes. Production automotive fuel cell power plants require all of these sensors to be on-board the power plant, and to provide data signals on a continuous basis to optimize fuel cell operation and protect the cell stack from damage.

Approach

UTCFC is, or will be, evaluating the sensors described above in the appropriate test facilities by supplying a synthesized gas stream of known inlet gas composition and determining the response accuracy of each sensor at the required operating temperature. By controlling the inlet gas composition and mass flow, a fixed reference will be established to which the sensor response will be compared as a function of time. This effort is being conducted in UTRC, IIT and UTCFC facilities. Baseline sensor technology taken from a combination of production PC25, S200 and fuel cell development laboratory applications is being subjected to a series of performance, durability and cost reduction studies. Concurrent with this portion of the task, a detailed review of alternate sensors is being conducted. New advanced solid state electrochemical and MEMS sensors are being developed at NexTech, Inc. and Advanced Technical Materials Incorporated (ATMI), which include new transduction principle development, new sensing materials and fabrication development, and sensor prototyping. Appropriate sensors will be ranked according to the probability of successful test outcome. Initial qualification tests will be conducted by IIT in the PEM Fuel Cell Benchmark Facility. These tests will consist of installation and exposure of baseline sensors to precisely controlled temperature, humidity, pressure, and gas mixture conditions. Sensor response versus these parameters will be logged.

Second level testing will be conducted at UTRC. During these tests, the sensors will be installed in a chamber through which gases simulating an autothermal reformer (ATR) exhaust stream (created by mixing gases, heating and humidifying as necessary, to obtain the desired composition) will flow. The sensors will be evaluated for accuracy, speed of response, cross sensitivity to non-target parameters and test gas parameters. The tests will operate continuously,

during which time a computer utilizing National Instruments LabView software will control and log all test parameters, including gas composition, sensor output, and control safety systems.

It is assumed that repetition of the above testing cycle will be required due to non-performance of some sensors. If baseline sensors cannot demonstrate performance meeting the targets in the HFCIT Multi-Year R,D&D Plan, alternates will be selected.

Results

A team has been assembled to address the development and evaluation of physical and chemical sensors meeting the requirements listed above. Table 1 shows the breakdown of responsibilities for each of the team members.

UTRC has constructed a physical and chemical sensor test facility capable of subjecting candidate sensors to gas compositions simulating operation in a gasoline/natural gas-fueled reformer-based fuel cell system. IIT will be evaluating all sensors developed during execution of this project in their PEM fuel cell test facility. The facility design is shown in Figure 1; Figure 2 is a photograph of the flow controllers, steam generator, and condenser.

UTRC has begun evaluation tests on a hydrogen sensor manufactured by H2Scan, Inc. in both dry and moisturized gas streams consisting of H_2 and N_2, with CO_2 and trace concentrations of methane added. Results of these tests are shown in Figures 3a and 3b.

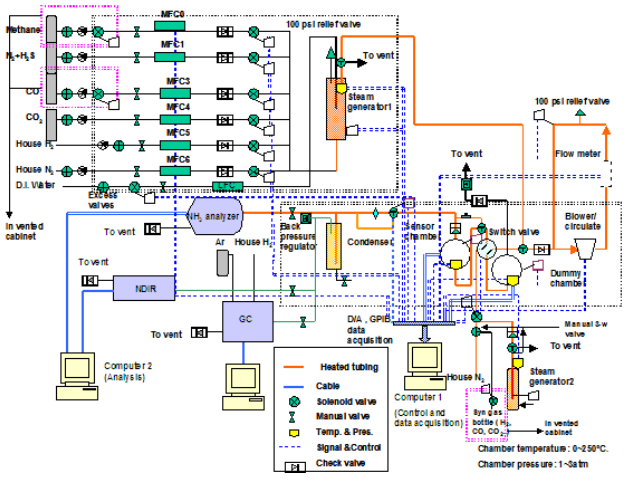

Figure 1. UTRC PEM Fuel Cell Gas Stream Simulator and Sensor Testing Rig

Conclusions

The tests show the H_2 sensor has a linear response to the concentration of H_2 present in the gas stream. The sensor indicates no cross-sensitivity to methane under the conditions investigated. The sensor shows excellent repeatability among the tests conducted so far. The sensor response time (t_{90}) in dry gas environment is about 30 seconds and the response time is extended to 100 to 140 seconds in a moisturized gas stream. The sluggish response as a result of operation in a humid environment may impact the cost-effectiveness of deploying the sensor in PEM fuel cells. This aspect of the overall sensor performance needs to be improved significantly.

Table 1. Sensor Development Team Responsibilities

Team Member	T	ΔP	RH	flow	O_2	CO	H_2	SO_2	H_2S	NH_3	Technological Expertise / Responsibility
UTC FC	X	X	X	X	X	X	X	X	X	X	Testing on S300 Breadboard
UTRC	X	X	X	X	X	X	X	X	X	X	Testing in reformate simulator
ATMI							X	X	X	X	Develop Using MEMS Silicon Microhotplate
IIT	X		X		X	X	X	X	X	X	Testing in Benchmark Facility
NexTech						X		X	X	X	Develop Using Solid State Electrochemical

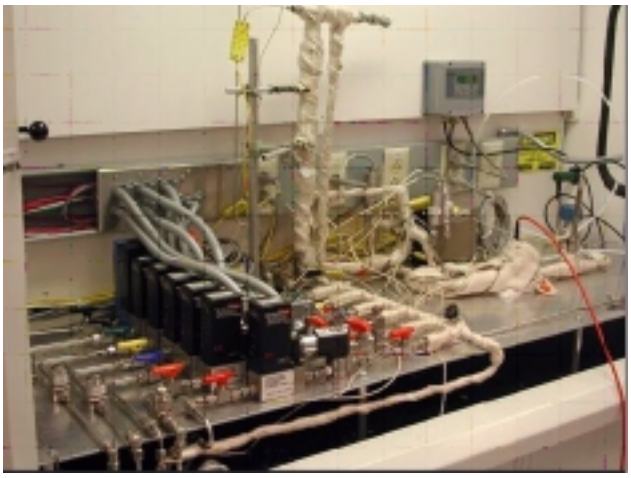

Figure 2. UTRC PEM Fuel Cell Gas Stream Simulator: Gas Flow Control System, Steam Generator, and Test Chamber

The candidate sensor selected for hydrogen detection has demonstrated excellent sensitivity and selectivity for H_2. The durability of the sensor is being tested in the simulated reformate stream.

Results of the physical sensor survey are summarized in Table 2.

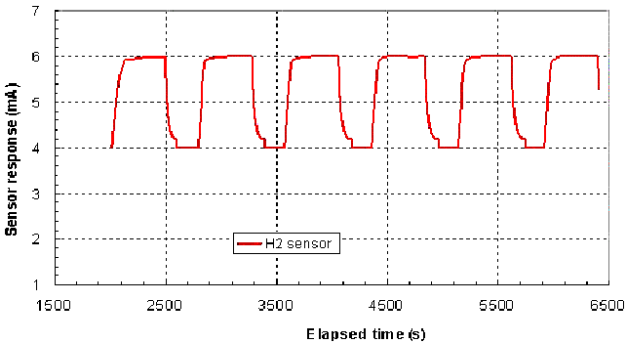

Figure 3a. Response of H_2 Sensor to Hydrogen in Dry Gas Stream

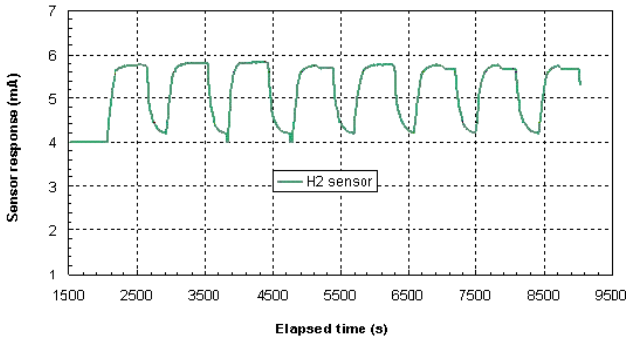

Figure 3b. Response of H_2 Sensor to Hydrogen in Simulated Reformate Gas Stream

Table 2. Results of Physical Sensor Survey

Sensor	*Meet DOE/FC tech. specs*	*Further effort*	*Technical gap/stretch*
Humidity	*Yes/Yes*	*Validate new technologies (MEMS sensor) to improve the recovery time*	*Medium*
Flow rate	*Yes/No*	*Collaborate with vendors to improve stability*	*High*
Differential pressure	*Yes/Yes*	*Collaborate with vendors for size and cost reduction*	*Medium*
Temperature	*Yes/Yes*	*Identify inexpensive thermistors for high temperature*	*Low*

References

1. DOE Workshop: "Sensor Needs and Requirements for Fuel Cells and CIDI/SIDI Engines," Robert S. Glass, Ed., published by Lawrence Livermore National Laboratory, April, 2000

2. Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan, June 3, 2003

3. "Solicitation for Financial Assistance Applications No. DE-RP04-01AL67057 Research and Development and Analysis for Energy Efficient Technologies in Transportation and Buildings Applications"; DOE Albuquerque Operations Office, November 21, 2000

FY 2003 Publications/Presentations

1. DOE Sensor Program 4th Quarter Review, submitted March 5, 2003.

2. DOE Hydrogen & Fuel Cells Annual Program Review, May 19-22, 2003